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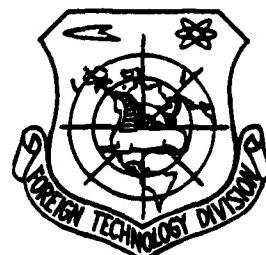
FOREIGN TECHNOLOGY DIVISION



DIRECTIONS OF APPLICATIONS OF COHERENT LIGHT OPTICS
AND HOLOGRAPHY IN GEODESY AND CARTOGRAPHY

by

Henryk Z. Kowalski and Adam Dubik



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FTD-ID(RS)T-1811-80

9 January 1981

MICROFICHE NR: FTD-80-C-001248

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English pages: 28

Source: Prace Instytutu Geodezji i Kartografii
VOL. 22, Nr. 1450, 1975, pp. 3-24

Country of origin: Poland
Translated by: SCITRAN

F33657-78-D-0619

Requester: FTD/TQTR

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WP-AFB, OHIO.

FTD -ID(RS)T-1811-80

Date 9 Jan 1981

DIRECTIONS OF APPLICATIONS OF COHERENT LIGHT OPTICS
AND HOLOGRAPHY IN GEODESY AND CARTOGRAPHY

Kierunki zastosowań optyki światła spojnego
i holografii w geodezji i kartografii

Henryk Z. Kowalski and Adam Dubik

Prace Instytutu Geodezji i Kartografii, Vol. 22(1(50)),
pp. 3-24, 1975

1. Introduction

Recent years have been characterized by a particularly rapid development of new mensuration techniques and methods with a decided effect on stimulating research work and on considerably increasing and streamlining production processes, expanding the possibilities for research on the micro- and macro-environments, etc.

This new approach to a number of research processes and immediately useful activity can be enhanced by providing new qualitative and more numerous information about the state of the material and the course of research processes, with simultaneous assurance of automation of these processes, fitting the requirements of clients, and of forms of processing, development and illustration of results.

Among the newest mensuration techniques, particularly wide opportunities and a wide range of applications are provided by the optics of coherent light and holography. At the same time, necessary for the development of these technologies are greater advances in mensuration electronics, which is their indispensable complement and a bridge between them and electronic computer technology, which must not be neglected in the modern comprehensive mensuration system for scientific and professional needs.

In the light of the above, the set of holographic technology, mensuration electronics and electronic computer technology constitute a logical path in research and mensuration processes and makes it possible to take a new look at the position and role of geodesy and cartography at the present time.

Currently the optics of coherent light and holography have limited possibilities in practical application in geodesy and cartography, but

nevertheless considerable progress in research has meant that a greater and greater number of research workers and teams, concerned with optics, geodesy and cartography, have begun research on practical applications in this field. The purpose of this article will be to present certain general methods and concepts which are currently found on the research level in leading scientific centers, with a discussion of the applications of coherent light optics and holography in geodesy and cartography.

The basic principles describing phenomena concerning coherent light and holography have been perfectly explained in many publications and books in our country and abroad [1-10].

Great speed in processing data, a tremendous information capacity, and the possibility of multidimensional and multichannel processing of information are only some of the benefits stemming from applications of optical apparatus using laser light and holography in geodesy and cartography.

Historically speaking, the leading role in adapting new physical phenomena to the development of mensuration methods and tools in geodesy and cartography has been played by photogrammetry. At the current state of development of coherent light optics and holography, its usefulness is increasing for traditional tasks faced by geodesy, and among which we can mention, for example, the measurement of distance and angle. Other examples of the possibilities offered by coherent light optics and holography are the results obtained in work on automation of processes securing aerial and satellite photographs, and photo-interpretation, where the quantity of information obtained, connected in particular with the development of satellite technology, is increasing tremendously.

2. Application of Coherent Light Optics and Holography in the Mensuration of Distance and Angle

2.1. Mensuration of Distance

A basic virtue of coherent light sources used in distance mensuration is the slight amount of divergence in a high-energy, monochromatic beam.

Robertson [11] states that it is possible to make a distance measurement with a relative error of 1/500,000, without considering errors caused by environmental effects.

2.2. Mensuration of Linear and Angular Displacement

In equipment known so far for measuring displacement, the essence of mensuration has most often been reading a gradation caused in a mechanical, chemical, optical or magnetic way, where equipment with auxiliary scales is used to increase the accuracy of reading, such as verniers, micrometric screws and optical equipment in the form of projectors and microscopes which increase the gradation.

A basic inconvenience with this type of equipment is the fact that the accuracy of the measurement is conditioned by the restricted resolution of the gradation and the significant influence of subjective error on the part of the observer.

Cases are known, for example Polish patent No. 54755, which make it possible to directly read the linear or angular displacement figures. However, the mensuration accuracy by means of these devices is limited by the accuracy of recording and reading, which does not exceed 300 bits per mm in the most perfect equipment of this type known. Further improvement in the accuracy of mensuration devices requires the use of special technology and additional

reading equipment, for example, electronic verniers, etc., which complicate the construction of apparatus, thus reducing the reliability of its activity, in addition to costing more.

In the IGiK [Institute of Geodesy and Cartography], equipment has been developed for the purpose of direct mensuration of linear and angular displacement figures with a tangible, simultaneous increase in the accuracy of this mensuration in comparison to results achieved with equipment known up to the present [12].

This task has been achieved by constructing measuring devices equipped with gradation with a very large density of marks, applied with great accuracy, and with an impulse generator which makes it possible to directly transfer linear or angular displacement on this scale into electrical impulses. Experimentation has shown that this type of gradation is realized most beneficially in the form of a hologram, i.e., by photographic recording of the phenomena of interference by coherent waves produced by a laser. This guarantees achievement of a gradation density on the order of several thousands of marks per mm, i.e., resolution of a magnitude which has been impossible to achieve in the past.

3. Possibilities of Using Coherent Light and Holography in Photogrammetry

3.1. Features of the Holographic Model

Just as in stereogram observation, an image of an object obtained with a hologram is characterized by three dimensions in the accepted arrangement XYZ. Photographing on the basis of a single, incoherent light source is used to obtain stereoscopic photographs. In the case of a hologram two coherent light beams are used: one, the so-called subject beam, and one a reference beam. The result of the interference of these two beams is recorded on high-resolution,

light-sensitive material. Reconstruction of the image of the object is obtained by illuminating the hologram with coherent light. The object image obtained is identical to the real object under the condition that light with a uniform wavelength and uniform wavefront is used. The "holographic model" achieved possesses good resolution capacity, as well as greater vividness in comparison to the stereoscopic model, thus creating new possibilities of enlarging this model. For example, it is possible to construct a new generation of apparatus (holoautograph) which makes it possible to use small-scale aerial photographs to develop large-scale maps, with a substantial effect on cost reduction.

Equipment especially constructed for the observation and measurement of a hologram will be simpler in comparison to current autographs for developing stereograms. All that is needed is a place to reconstruct the hologram and a coordinatograph associated with the movement of the scale mark.

The preparation and recording of holographic stereo models make it possible to use mensuration systems more efficiently, the result of the possibility of recording many stereo models on a single plate of light-sensitive material. This permits a new approach to the problem of photograph orientation.

The base of observation, in contradistinction to the observed holographic model, can have its position changed, as a result of which it is possible to observe it from different sides. If, for example, a particular feature of the object is shaded by another, it is sufficient to move the observation point to make this detail visible. This is one of the main differences existing between the stereoscopic model and the object reproduced from the hologram. All changes in the reconstruction beam, compared to the beam used to record the hologram, cause corresponding changes in the brightness of the model, leading

at the same time to geometric changes. In cases of small changes in wavelength, concomitant errors are of a linear nature and geometric fidelity is preserved.

The hologram and photograph contain definite information about the holographic object and are similar in many respects, while they differ in others. It appears useful to make a comparison of the properties of a hologram and photograph with particular stress on photogrammetric aspects.

Common features and differences between a photographic picture and a hologram are presented in Table 1 [13].

Table 1

Hologram	Photogram
1. A lens is not necessary to obtain a hologram.	1. All radiation coming from the object goes through a lens.
2. The concept of focal length does not occur.	2. Focal length plays an important role. The scale and plane of the object depend on it.
3. The amplitude, phase, frequency and polarization state of the wavefront diffused by the object can be recorded.	3. The intensity of the light, expressed in the form of changes in photographic emulsion opacity and frequency, are recorded, containing information about color in the case of a colored photograph.
4. Distance from the object has no effect on the formation of a hologram.	4. Distance has an effect on the photographic image.

Hologram

Photogram

- | | |
|---|--|
| 5. A hologram records an object equally sharply at every depth. | 5. The image is sharp only within the limits of the depth acuity of the lens. |
| 6. The image of the object is recorded in a "coded" (interference lines) form. | 6. The image of the object recorded on the plate corresponds to the real object. |
| 7. A coherent light source is necessary to record the image. | 7. A coherent light source is not necessary for photographing. |
| 8. Resolution is uniform for the entire hologram. | 8. Resolution is not uniform for the entire plane of the photograph. |
| 9. High stability is required of the apparatus used to make the hologram. | 9. Requirements on the stability of the object and the camera are less. |
| 10. The use of holographic material of high resolution capability is necessary to achieve a high-quality hologram. | 10. The use of photographic materials with a resolution capability on the order of more than 50 l/mm is necessary to obtain a good photograph. |
| 11. There is a possibility of obtaining images by means of microwave holography or ultrasound holography, making it possible, among other things, to penetrate living organisms, etc. | 11. There is a possibility of obtaining images at different wavelengths by means of special technologies. |

- | Hologram | Photogram |
|--|---|
| 12. The spatial model of an object is obtained on the basis of a single hologram. | 12. A single photograph does not produce a spatial model. Two stereoscopic photographs are necessary. |
| 13. The reconstructed model can be of a high class under the condition that the hologram is observed under the same conditions as at the moment of exposure. | 13. The stereoscopic model produced from two different photographs is affected by aberration. |
| 14. Every point on the hologram participates in recording the entire object, and every point of the object is recorded on the entire plane of the hologram. | 14. Only one point on the photograph corresponds to one point on the object. Therefore a fragment of a photograph contains information only about a fragment of the object. |
| 15. A reconstructed hologram produces two images: an apparent one which can be observed with the unaided eye, and a natural one which can be fixed directly on a photographic plate. | 15. An orthoscopic, a pseudoscopic and a zero model can be obtained from stereoscopic photographs. |

- | Hologram | Photogram |
|--|--|
| 16. The observer sees the image of the object by means of the hologram. The object is reconstructed beyond the plane of the hologram (in the plane of the hologram for a hologram with a focussed object). | 16. In the case of observation of:
a) a single photograph the observer sees the model in the plane of the photograph,
b) a stereogram in any position with respect to the reference plane. |
| 17. It is possible to observe the holographic model from various points in space (inspection of objects shaded in a previous plane). | 17. The masking effect occurs on the photograph as a function of topography. |
| 18. Magnification can be on the order of $10^5 : 1$. | 18. Enlargement of the photographic image is limited by the graininess of the emulsion. |
| 19. A positive image is obtained by holography. | 19. Mainly negative. |
| 20. Copying a hologram mainly produces a positive image. | 20. Copying a negative produces a positive. |

3.2. Spatial Model Measurements Obtained from a Hologram

When the use of holography in photogrammetry was proposed for the first time, the attention of researchers was concentrated on using the holographic stereo models for cartographic purposes. Work conducted at Purdue University E. M. Mikhail [14] and M. K. Kurtz [15] presented the first results of using holographic stereo models.

Glaser and Mikhail [16] and Gifford and Mikhail [17] have performed research concerning determination of the accuracy of measurements by using holographic stereo models. Balasubramanian and Stevenson [18] demonstrated possibilities of using holographic stereo models in topographic cartography.

The results obtained by Gifford [19] are very promising. He determined the accuracy of measurements from holographic stereo models. This accuracy is of the same order as the accuracy obtained by means of traditional methods. This research requires an operator directing the measurement marker on a holographic image. The possibilities of obtaining similar accuracy in the case of completely automatic measurement apparatus with a holographic stereo model have not yet been determined, but it is nevertheless assumed that the accuracy will be increased. Work is proceeding in this direction.

A major technical problem at this stage of the development of holographic techniques is concerned with the recording of holographic stereo models and the possibility of recording and reproducing microholographic stereo models.

The problem of measurement automation is also involved with the use of a coherent light source and holography. S. I. Krolikowski and D. C. Kowalski [20] have begun work in this direction.

This comes down to determining the parallax occurring on a stereogram with the help of an optical colorimeter, in which laser light is used as an information carrier.

The correlation method for determining the photogrammetric parallax is based on the use of a discriminating filter (holographic recording of a Fourier spectrum) for one of the stereoscopic photographs and the insertion of the second of the two photographs into the entry of the optical apparatus. In the exit plane of the apparatus is formed the so-called correlation function of

the two photographs, and the mensuration of its coordinates provides an answer to the question about the parallax values.

The above determination refers to any point on the photograph.

Basic advantages of the method based on this concept are its simplicity in execution and the great acceleration in obtaining and recording data associated with relief on the ground, while its basic disadvantage is the difficulty found in precise determination of the coordinates of the basic maximum of the correlation function, which has a decided effect on mensuration accuracy. For the purpose of enhancing the accuracy of parallax mensuration, work [21] proposes a new method of obtaining and measuring this, using a reverse holographic filter, thanks to which the exit plane of the coherent optical apparatus (KUO) does not produce the correlation function of the stereoscopic photograph as in the correlation method, but rather the so-called Dirac (impulse) function. This enables more precise determination and mensuration of its coordinates, and in this very way a manifold increase in accuracy.

Another advantage of the proposed solution, which is the object of this paper, is simplification of the optical apparatus fulfilling the method, thanks to recording the operator lens along with the reverse holographic filter.

The reverse filter used in the method given in the cited work can also be used to improve the quality of photographs distorted, e.g., as result of improper camera focus or movement of the object during the exposure period.

Simple coherent optical apparatus using holographic filters increases the chance of rapid processing of cartographic data. The points of overlap of the stereograms and the measurements of the image parallax, of interest to us, are obtained as a result of shifting the coherent beams in the plane of the first photograph. The method proposed for determining the parallax differs

essentially from existing holographic methods. The discriminating filter is replaced by the reverse filter, thanks to which only the phase part of one Fourier image from the stereogram takes part in the formation of the output signal.

In this case the output signal is Dirac's δ function. It is easier to determine and measure its coordinates than the coordinates of the correlation function in the discrimination filter method, which may determine secondary maxima. This increases the accuracy of the method. Use of cylindrical optics for the proposed method enables determination of parallax at the same time on a chosen sector of relief stereograms.

It seems expedient to recall the method of the quasi-Fourier filters developed in Poland, used for securing the stereographic model on the basis of stereograms [22]. It is a well-known fact that an optical apparatus, e.g., a stereoscope, which must be properly correlated with the position of the photograph, must be available in order to obtain the effect of depth on the basis of observation of photographs. In order to be able to execute a stereogram, there must be photographs which, in the majority of cases, have a large surface and therefore small information density. Among other reasons, this is the result of the limited possibilities of recording a large number of photographs on a small surface. Neither is it possible in producing stereograms to expose several projections onto the same spot of light-sensitive material because of obvious concern over getting an illegible photograph or otherwise a loss of information.

The following question naturally comes forward in connection with the deliberations mentioned above: would it not be possible to eliminate from the procedure of processing stereograms the optical apparatus, which produces a number of distortions, such as aberration, absorption, etc., affecting the

range of mensuration errors, among other things, and simultaneously to enable collection (registration) of a larger number of data than in using the traditional method? Is it possible (and this may appear absurd) to expose a larger number of photographs to one and the same place on material without fear of losing information? And finally we have a general question: is it possible to find (or does there exist) a more modern, more accurate and more economic method?

We are able to give a positive answer to all of these questions and doubts about holography.

If a spherical beam of coherent light falls on lenses as far apart as the distance equal to the optical base, Fourier spectra will be formed from stereograms π_1 and π_2 in a plane at a corresponding distance from the lenses.

In the case of two photographs π_1 and π_2 these spectra will have interference from lateral waves called in holography reference waves (beams). After exposure and processing of the photochemical light-sensitive material, holograms of Fourier stereograms will be recorded in the spectral plane in two places on the light-sensitive material. A larger number of stereograms can be recorded in the hologram by changing the pair of stereoscopic photographs and shifting the hologram by a small extent. In this case the diameter of the hologram speck cannot exceed 0.5 mm. It should be noted that the diameter of the specks is inversely proportional to the scale of the stereoscopic photographs and depends on the number and type of details contained in the photograph.

To record all of the component frequencies in a Fourier spectrum it is necessary to make holograms at a certain distance from the "ideal" focusing point of the lenses. Such exposure produces increased resolution in the

reconstructed images. In order to even further increase the capacity of a holographic "bank" of stereoscopic photographs, it is possible to make many exposures of different stereograms in the same place, without changing the position of the hologram but changing the angle of incidence of the reference waves. The one condition for making a proper record is stability in the curvature of the surface of the reference wavefront for stereograms of Fourier spectra. Light-sensitive material exposed in this way and then properly developed and fixed, must be illuminated by a pair of beams falling as closely as possible at the same angle as that of the reference beam during registration.

In making observations (left eye, left holostereogram; right eye, right holostereogram) we observe that in places where there were stereograms when the holograms were recorded, the images of these stereograms are reconstructed, with figure #1 reaching the right eye and the figure of the left stereogram #2 reaching the left eye. In this way we can observe a spatial model, and also make necessary measurements by means of light mensuration marks. No additional optical equipment is necessary for the above-mentioned description of stereogram reconstruction.

Changes in the scale of the reconstructed photograph can be made either by changing the wavelength of the light reconstructing the holograms or by changing the curvature of the wavefront.

Now we can already safely say that a new direction has been formed, representing one of the many recently developed measurement technologies, named hologrammetry and proposed in a collective work [15]. Hologrammetry thus embraces:

- a) the elaboration of holograms of small objects, and
- b) the elaboration of holographic stereo models.

Thus it can be expected that, just as a stereogram is currently made cartometrically, we shall soon be able to make a hologram. Obviously the holographic technology will not completely supersede or replace traditional photogrammetric methods, but will undoubtedly supplement them with new possibilities [24-34].

4. Holographic Collection of Information, Optical Memory

Optical memories can be compared to memories in digital computers or, in their simplest form, optical memories can refer to materials which record optical signals. In geodesy and cartography the possibilities of using optical memories or holographic recording materials are becoming more and more realistic. Information in the form of digital and analog data from graphic sources and from spatial images can be stored in economic archival memory systems, enabling them to be used immediately and also permitting more rapid access in comparison to conventional data storage systems.

The great interest in optical memories is justified by the fact that the density of information collected is theoretically limited only by the wavelength of the light used in the recording process. For volumetric recording this value amounts to 10^{12} bits/cm³, while in bidimensional recording it is 10^8 bits/cm² [35]. In reality the possibilities of collecting information are less by several orders of magnitude because of the practical limitations which occur, such as diffractive decomposition, interference of optical apparatus, deflection from the recording surface or the focal length plane, dust, cracks, and defects in material. Many of these limitations can be overcome by using holographic methods of recording.

There are interesting examples of the optical storage of information. For example Bardes [36] discusses the possibilities of holographic storage of

colored maps and restorative apparatus, Amodei [37] stored colored images in volumetric holograms as a function of saturated lithium niobate, and Staebler [38] described the storage of 100 holograms with the possibility of reading, recording and storing them in such materials as those mentioned above. It seems to us that this is the opportune moment to begin serious examination of optical memories and the possibilities of using them in cartography. Current capabilities of recording materials, described by McMahon [39], permit the storage of information up to 60 sheets/cm² on thin holograms, and Palermo and Vander Lugt [40] discuss a holographic storage system, man reading-machine reading, where a surface 10 x 15 cm was used for storing 2×10^7 bits of information.

Reproduced parts of a map must have an accuracy within the limits of 0.1 mm and almost perfect uniformity in shading with respect to the format containing all of the source information, and that is why scientific research is needed to determine the possibilities of storing cartographic information.

At the present time every decade doubles the amount of scientific and technical information [13]. A similar situation holds in geodesy and cartography, where the number of different kinds of documents is multiplying like an avalanche because of the intensive development of these fields. This situation is engendering a serious crisis in the possibility of storing information of this type. The development of equipment to record and read information by using microfilm is an attempt to solve this crisis. However, this has created great technological difficulties in the area of optics, found in the high cost of this equipment which obviously limits its general use. In this situation the occurrence of holographic methods of collecting information opens new possibilities in this area.

The fidelity of information in a reproduced image depends to a large degree on the surface of the hologram containing the image. So-called coherent noise (speckle structure) resulting from the properties of the coherent light, has a decided effect on the quality of an image.

In practical applications it is not always necessary to record complete information about an object. For example, if an object is "a slide of a map" (this type of object is a typical example of information material requiring collection), gradation (grayness of various tones) in individual lines or background is less essential. Conventional holography makes it possible to eliminate needless information in recording. However, there is a method of projecting information onto the recording surface, enabling spatial filtration of certain features of information, known as Fourier transformation and achieved in optical apparatus by means of magnifying lenses. The use of this transformation in holographic recording of optical information determined on the plane called the subject plane depends on holographic recording made in the plane of the focal length of the optical apparatus. In this plane the zero line of the light deflected onto the structure of the object is connected with a steady optical density in the reproduced image, while other diffractive rows are a function of figure contrasts. In addition, the smaller the detail of the object, e.g., line thickness, the greater the gaps between the individual diffractive lines in the spectral planes. Therefore a small holographic recording surface in a Fourier plane, constituting the environment of the diffractive center of the image, somehow automatically eliminates undesired details and slight irregularities in the object, but at the same time reduces the contrast of the reconstructed image. Suitable optimization of the recording surface is possible [1] by exposing only essential informational content of the object, and dependent on the method of illustrating it in the reproduction process,

among other things. The parameters of the optical apparatus achieving the Fourier transformation also play an essential role in the process of minimizing the surface of the microhologram. The smaller the relationship between the focal length and the input lens of this apparatus, the smaller the amount of surface which can be used to record while maintaining the same quality of image reproduction. In addition holographic recording in diffractive lines separated by planes obviously has an essential effect on minimizing the speckle structure. In practice the photographic plate is shifted in a plane slightly shifted with respect to the Fourier plane in order to reduce the effect of the nonlinearity of the characteristics of the light-sensitive material on which the microholographic recording is performed. This guarantees more regular distribution of light intensity on the emulsion, without producing overexposure in the area of the diffractive zero line nor underexposure in the area of the higher diffractive lines. Such holograms are called quasi-Fourier holograms.

An advantage of this method of recording is the ability to reproduce information with a possibility of making changes in the scale of the reconstructed images by using a beam of varied divergence (or convergence) in the reconstruction.

Another method of recording and reproducing a microhologram is based on holographic recording in the plane of the focal length of the optical apparatus, forming an enlarged real image, and on the reproduction of the already enlarged image by illuminating the hologram with a beam identical to the reference beam making the record. This method of holographic collection of information seems to have a basic practical edge over the method previously described. In truth, because of the great magnification, this apparatus requires the use of optical elements of high quality but, in contradistinction to the previous method, it does not need optical elements compensating for aberration in the reproductive apparatus.

The possibility of considerably reducing the costs of equipment to reproduce information by eliminating the laser from it plays a great role in extending the use of the microholographic system of collecting information. The different method of recording information produces this possibility. The difference with respect to the apparatus described above is based only on the fact that the reference beam falls precisely in the contrary direction, and that the emulsion is thick enough for a large number of equiphasic interference layers to be formed in it. As is known, after development a photographic plate is a special kind of selective interference filter and, when it is illuminated by a beam of white light, configured identically to the recording reference beam, it produces a real enlarged figure in the plane optically opposed to the subject plane with the color possessed by the light used for recording. In comparing the microholographic method to the microfilm method of collecting information, the following features of the microholographic method can be enumerated:

1. The figure is recorded on the hologram in a coded form.
2. Holograms are less sensitive to dust and scratches.
3. Optical apparatus is missing in the reconstitution of images from microholograms.
4. There is a great degree of tolerance with respect to the accuracy of placing the plate with respect to the laser light beam.
5. The process of duplicating holograms is not complicated.
6. There is the possibility of recording several images with the capability of reproducing them individually, in one and the same spot on a hologram.
7. There is the possibility of using materials enabling repeated recording and dropping of data.

8. Low costs for equipment for recording and reading information.
9. A large information density is recorded in comparison to the surface or volume of the light-sensitive material.

5. Holographic Methods of Recognizing an Image in Photointerpretation

Application

5.1. Holographic Filtering

Black and white aerial photographs with a surface of about 58 cm^2 can contain up to 10^{12} bits of information with the precision and resolution necessary for cartography. In the case where thousands of individual photographs must be taken to cover a given area, processing the information contained in such a number of photographs by a digital method constitutes a problem. In such cases it seems expedient to process the information by using optical coherent analyzers [49, 50].

Therefore there is a need to produce works favoring the construction of apparatus which, for example, can automatically distinguish and classify source material obtained with respect to content in the form of its representation on a map. Another task of this equipment is to recognize and classify changes occurring in time and applying them to map updating. The apparatus also makes it possible to eliminate undesirable effects of atmospheric conditions, e.g., clouding or defects in apparatus, in effect producing, e.g., an overexposed image or one leading to errors in the scale of photographic images with a large information density. Further work must be carried out for the purpose of obtaining the optical flexibility which electronic correlators have.

Image-image correlators are suitable for use to determine points of opposition in stereo figures, while image-discriminating filter correlators are better adapted to problems associated with the detection of images.

Feinlieb [23] proposes a plane modulator of spatial frequency to form real-time discriminating filters. Differentiation of natural data about terrain in spatial images causes enormous difficulties in preparing model discriminating filters for recognizing terrain images. Rotz [41, 42] has proposed precise research with an image-discriminating filter correlator for automatic plotting of photographs.

It is a well known fact that the process of identifying aerial photographs made from low photographing altitudes is very labor intensive and requires deep familiarity with the subject on the part of the photointerpreter, as well as a great deal of perceptivity. Therefore this work should be automated. Automation of the identification process is based on detecting different kinds of objects in photographs, determining their coordinates and numbers, and other data by means of special equipment. Thus the goal of photointerpretation automation is to secure the optimal amount of information on objects and situations of interest to us, such as can be formed by the use of holographs and coherent apparatus for processing information.

The objects to be identified in photographs can be divided into random and determined objects. Adequate methods of identification are used as a function of these objects. The methods used are based on principles of spatial frequency filtering. Since a broad view of identification methods has been given in the article, we shall limit ourselves to showing how coherent optical apparatus can connect a photograph with a map.

One of the best-known methods is the correlation method [43-47].

If by the concept "signal" we understand a photograph of interest to us (a link which we must make) found with other known photographs, the standard of resemblance in the photograph interesting us and the known photographs

(the coordinates of which are defined on a map) will be a function of correlation maximizing the signal-interference ratio. This function can be obtained by using optimal and discriminating filters, produced by holographic methods. The correlation function assumes maximal value in cases where two identical images (photographs) are compared, and the least value in the process of comparing identical images. This is the very principle used to subordinate known photographs to an unknown photograph, and photographs with coordinates known to us to a photograph with undetermined coordinates on a map.

The above illustrates that, in order to be able to effectively identify objects in a photograph, a memory matrix of holographic discriminating filters must be available.

Automated devices used to identify terrain photographs, and which can be used for other purposes, will certainly be built in the coming years. However, coherent optical devices for special purposes, performing simple tasks, already exist. Coherent optical methods of mutual penetration are used to identify more complex images, but in the long run they will be replaced by automated apparatus constructed of connected optical-digital, hybrid, computers.

5.2. Directional Filtering and its Use

5.2.1. Description of the Method

If we introduce information in the form of a photograph into a parallel beam of coherent light emitted by laser, the amplitude-phase decomposition of its course (diffractive model) in the infinite course of this beam will correspond to the Fourier transformation of the Fourier function of the photograph, i.e., a Fourier spectrum with two spatial coordinates. Information recorded in the photograph is usually called the subject function, and the plane of introduction of the photograph into the laser beam is called the

subject plane. The Fourier spectrum is formed in the spectral plane. The plane of the spectrum is characterized by the coordinates of the spatial frequencies. Introducing a regular focusing lens into the course of the laser beam causes the Fourier spectrum of the subject function to be transferred from infinity into the plane of the focal length which becomes the spectral plane.

This spectrum can easily be observed on a screen, e.g., a mat plate, and also photographed or measured by means of photodetectors. It is also possible to place other kinds of amplitude filters into the spectral plane, affecting the filtering of corresponding frequencies of the subject function, meaning a weakening or intensification of the signals interesting us in the initial photograph. Purely phase filters can be introduced causing information to be obtained in the output image with definite local displacement corresponding to the input photograph, and it is also possible to introduce amplitude phase filters, e.g., optimal and discriminating filters made by the holographic method used to identify objects in photographs or to improve photograph quality. Without having recourse to begin with in an analysis of problems of spatial frequency filtering, we shall examine a few basic properties of these same Fourier spectra.

Let us imagine a photograph of a series of simple lines parallel in a certain direction. By introducing such a photograph (the subject function) into the subject plane of a coherent optical device composed of a focusing lens, illuminated by a parallel beam of laser light, we obtain a Fourier transformation of these lines in the spectral plane. Observation of the spectrum leads to the conclusion that all of these lines are completely concentrated on a single simple straight line perpendicular to the direction of the lines in the initial photograph. A point of light with a normally large concentration of energy is

found at the beginning of the set of coordinates of the spectral plane. This point represents the focussed radiation which was not subject to diffraction at the subject function of the photograph.

Despite this and as a function of the form of the photograph (rectangle, circle) the Fourier spectrum of the subject function can yield curves or concentric circles which, however, do not interfere with the interpretation of the spectrum because of their small dimensions compared to other elements. With closer observation of the spectrum we find that it is symmetrical to the beginning of the coordinate set or to the center of the diffraction model.

If the lines mentioned are parallel, and regularly distributed on the photograph, the Fourier spectrum is also round and regular, and concentrated in the form of parallel points on the perpendicular to the line in the initial photograph. The distance between these points is inversely proportional to the distance between the straight lines. This is a result of the fact that a smaller spectrum corresponds to a larger photograph and a larger spectrum corresponds to a smaller photograph. Illuminating a photograph containing a line produces a type of effect where the Fourier spectrum blots out the bright central point, (i.e., the zero line of the spectrum), as well as the information on the type of form of the photograph. In case the parallel lines do not possess regular intervals, the spectrum will also be concentrated on the line, but not circularly as in the previous case. It is defined a little worse, and obviously contains asymmetry in accord with its center. With a greater irregularity in lines in the photograph, also expressed by a loss of local parallelism, the Fourier spectrum "bulges" around this straight line. Expansion of the spectrum increases with the increase in irregularity. An analysis of the spectrum model of the undulating surface of water has led, among other things, to a special interpretation of the nature of wave activity on the seashore and even on the relief of the bottom.

In certain cases this enables a map of the sea bottom to be made on the basis of changes in the image of ocean waves.

The use of an analysis of photographs of the Fourier spectrum instead of analysis of the photographs themselves can be applied, e.g., in evaluating the specific density of population in urban space, average construction dimensions, determination of the number of available transportation routes or the dominant directions of these routes [48].

Photographs to be used for interpretation can obviously be subjected to initial processing, such as, e.g., filtering of useless information or differentiation of the subject function, corresponding to presentation of objects in photographs in the form of their contours. In many cases operations of this type facilitate the photointerpretation process, and are sometimes actually indispensable for proper evaluation of situations in photographs of interest to us. This occurs, for example, in automatically measuring the dimensions of building construction or population density, where the limits of light diffraction embrace walls, garden fences, streets, squares, etc. It is also found in determining the dominant directions of communication routes, where information on water routes can interfere with information on railroad lines.

6. Improving Photograph Quality

In many cases it is necessary to improve the quality of photographs which have been distorted in various ways. Laser light plays a significant role in these problems. It is an information carrier (after conversion through a modulator) which can be subjected to the activity of a Fourier operator, for example, and then properly filtered for the type of distortion.

I. Let us examine a case in which a photograph has been distorted as a result of overexposure. This photograph can be described as the sum of the non-distorted photograph function and a certain constant. By making a Fourier distortion in the spectral plane we obtain the sum of the spectra of the non-distorted photograph function and of the spectrum of the constant, which occurs in the form of a Dirac δ function at the point with coordinates $(0,0)$. By placing the opaque speck at this point, the constant component can be stopped while the spectrum of the non-distorted image is passed on. The non-distorted image is obtained by converting the signal through the following Fourier analyzer.

II. If the distorted photograph is a circular component, e.g., a screen network, it can be removed by performing a similar filtering operation. Depending on whether the photograph and the interference are the sum or product, the two Dirac δ functions are blocked in the spectral plane or the image contained at lines \pm_1 is passed on.

III. Spatial frequency filtering can also be used to reconstruct an object from a distorted photograph by any curved or rectangular movement of the photographic object or photographic apparatus. In this case the movement or displacement of the photographic object must not be uniform. It can be movement at any velocity. It can be demonstrated that lack of clarity in a photograph caused by movement of the object is described as a function of the interference of the non-distorted object and of the function describing the path of displacement. The interference subject to a Fourier operator gives the product of the spectra of the interference functions in the spectral plane. This product contains the spectrum of the signal distorting the photograph. It can be removed by using in the spectral plane a filter describing the reverse function in relation to the distorted signal.

There are works on the application of the holographic filtering method to improve distorted photographs, e.g., as a result of poorly focussed apparatus.

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